AD 740767

# CARBON MONOXIDE LASER

# QUARTERLY TECHNICAL STATUS REPORT

prepared by

AVCO EVERETT RESEARCH LABORATORY
a division of
AVCO CORPORATION
Everett, Massachusetts

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## FOREWORD

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| ARPA Order No.: | 1807 |
| Name of Contractor: | Avco Everett Research Laboratory |
| Effective Date of Contract: | 1 November 1971 |
| Contract Expiration Date: | 30 December 1972 |
| Amount of Contract: | $201,220 |
| Contract Number: | N00014-72-C-0030 |
| Principal Investigator and Phone Number: | Dr. Robert E. Center<br>Area Code 617, 389-3000, Extension 593 |
| Scientific Officer: | Director, Physics Program, Physical Sciences Division, Office of Naval Research, Department of the Navy, Arlington, Virginia 22217 |
| Short Title of Work: | Carbon Monoxide Laser |

## SUMMARY

The main objective of this program is the investigation of pulsed electrical CO lasers to determine their potential scaling to large scale, high power operation. The program is based on the application of the electron beam ionizer-sustainer concept to the vibrational excitation of CO with temperature controlled operation.

The following areas of investigation are included in the current contract:

1) Investigation of the electron beam current requirements and the E/p range for sustainer discharge excitation of CO and $CO/N_2$ mixtures.
2) Design and construction of the electron gun and laser cavity for operation at gas temperatures from $80^{o}K$ to $300^{o}K$.
3) Experimental investigation of the multiline/multimode operation over a range of gas temperature and pressure up to the equivalent of one atmosphere at room temperature.
4) The extension of the theoretical model to the directly excited CO laser including calculations of the transient gain and power.

During the first quarter of the contract the following technical results have been achieved:

1) The design and construction of a 1 meter long broad area electron beam and power supply. Initial limited performance tests have yielded current densities of up to $100 mamp/cm^2$ from the electron gun.
2) The design of a cavity with temperature controlled discharge electrodes and a variable temperature gas source.

3) Small scale electron beam experiments have been made to measure electron-ion recombination rates for discharges in CO at pressures of up to one atmosphere.

4) Work has begun on the extension of the steady-state theoretical model to the pulsed CO laser excited by direct electron impact.

In the next quarter it is anticipated that the entire laser experimental apparatus will be completed provided there are no major delays in the fabrication of the variable temperature discharge electrodes. Measurement will be made of the temperature uniformity in the cavity including transmission measurements using a probe He/Ne laser. Initial laser performance tests will then be made using a multimode cavity configuration.

# I. INTRODUCTION

The CO laser program has the objective of investigating the performance characteristics of the pulsed electrical CO laser using the electron beam-sustainer discharge excitation scheme. The experimental investigation is intended to cover a wide variation in gas temperature, from $80^{o}K$ to $300^{o}K$, to observe the expected enhancement of the lasing output with decreasing translational temperature. The development of a theoretical model of the complex multi-vibrational level system is included in the overall program to provide support for the design of the apparatus and the interpretation of the experiments.

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4) Work has begun on the extension of the steady-state theoretical model to the pulsed CO laser excited by direct electron impact.

The variable temperature discharge electrodes are in the process of fabrication and their delivery is expected in the next two months. It is anticipated that the entire experimental laser apparatus will be completed in the next quarter. Measurements will be made of the temperature uniformity in the cavity including transmission measurements using a probe He/Ne laser. Initial laser performance tests will then be made using a multimode cavity configuration. The proposed program schedule is shown in Fig. 1. The initial laser tests should be on schedule provided there are no further delays in the fabrication of the discharge electrodes.

## II. 500 JOULES/PULSE EXPERIMENT DESIGN

An experimental CO laser is being designed and built with the aim of producing 500 joule/pulse multimode output energy in approximately 100 to 1000$\mu$sec. The device, shown schematically in Fig. 2, includes the following components:

1) Broad area electron beam source designed for operation up to 150 m amps/$cm^2$ with electron energies up to 150 kV.
2) An electron beam power supply incorporating a 1.5$\mu$F capacitor bank with a 0-200 kV charging power supply.
3) Control circuitry for pulse modulating the electron beam current.
4) A sustainer capacitor bank of 25$\mu$F capable of operation up to 60 kV with a stored energy of 45 k joules. This bank is intended to provide the sustainer pulse with a minimal voltage drop.
5) Temperature controlled anode and cathode electrodes for the sustainer discharge. The cathode is being designed as a semi-porous structure with cooled gas being supplied through this structure.
6) A cavity box to house the discharge electrodes and cavity optics. This structure will be evacuable.
7) Multimode optics.
8) Heat exchanger for the gas supply.

Items (1) through (4) have been built and were assembled by the end of the first quarter. Initial performance tests have been made on the E-Beam assembly and current densities up to 100 mamp/$cm^2$ at 130 kV have been measured. The cavity box has been machined and is currently being assembled. The anode and cathode structures have been designed and ordered. Considerable delay has been experienced in the

delivery of the components for the porous cathode assembly. It is anticipated that the initial operation of the system will be on schedule as shown in Fig. 1 provided there are no further delays in the fabrication of the cathode structure.

## III. SMALL SCALE EXPERIMENTS

The electron beam current necessary to produce a specific electron density in the gas depends on the ionization cross section for electron impact and the rate of loss of electrons by recombination and attachment. While the ionization cross section has been previously measured, there is virtually no data on electron-ion recombination rates in CO, particularly at high pressures where one might expect the dominant ion to be a polymer ion $(CO)_n^+$, $n \geq 1$.

An existing small scale electron beam-sustainer experiment was used to study the recombination and attachment process in both pure CO and $CO/N_2$ mixtures at pressures up to one atmosphere. The apparatus has been previously described in AERLP 984 and consists basically of a 250 $cm^3$ discharge volume with an E-Beam of 50 $cm^2$ area. A 5$\mu$F capacitor is used to supply the sustainer discharge at voltages up to 60 kV. Since the attachment of electrons in the gas discharge can be dominated by gaseous impurities, in particular $O_2$, considerable care was taken to eliminate leaks from the discharge region. The leak plus outgassing rate was found to be less than 2$\mu$ Hg/minute.

Initial experiments in pure CO resulted in considerable electron attachment as indicated by the shape of the sustainer current characteristic (discussed below). This attachment was much too large to be attributed to the $O_2$ resulting from leaks as well as that present in the CO (Mathieson Ultra High Pure). The gas was sampled directly from the discharge volume and I. R. absorption spectra taken. These indicated the presence of an impurity in the wavelength range of 4.9 to 5 microns which was subsequently identified as $Fe(CO)_5$. The iron penta carbonyl could be partially removed by passing the gas through a heated copper coil. Several different cylinders of CO were then tested, some of which showed anomalously high carbonyl content, as high as 50 ppm. Subsequent measurements were made with the "cleanest" bottle in which the carbonyl content was not detectable in the I. R. absorption cell indicating

a concentration of less than 5 ppm. Despite the apparent purity of this bottle, some attachment was still observed which is attributed to the presence of trace quantities of the carbonyl or other unidentified impurity. This conclusion is based on the known large attachment cross section for Fe $(CO)_5$ and the absence of any evidence of the existence of $CO^-$.

The electron-ion recombination rates and electron neutral attachment rates are derived from measurements of the sustainer discharge current transients following the step-wise onset and cutoff of the E-Beam. Typical current profiles are shown in Fig. 3. The sustainer voltage is applied prior to the E-Beam pulse and the discharge is initiated by the E-Beam pulse which approximates a top hat profile with rise and fall times of the order of 1 $\mu$sec. The electron density in the discharge is determined by

$$\frac{dn_e}{dt} = P - \alpha n_e n^+ - \beta n_e$$

where P is the rate of production of secondary electrons in the primary ionization process, $\alpha$ and $\beta$ are the recombination and attachment coefficients, respectively and $n_e$ and $n^+$ are the electron and positive ion densities. The negative ion density is determined by charge conservation

$$n^- = n^+ - n_e$$

and its rate of formation is given by

$$\frac{dn^-}{dt} = \beta n_e - \gamma n^- n^+$$

where $\gamma$ is the ion-ion recombination rate.

For pure CO the attachment terms in the above equation would be zero and one could readily integrate the electron production equation to yield the expected profiles during the onset and cutoff characteristics. No simple analytic solution is available in the presence of electron

attachment because $n_e \neq n^+$. However if the attachment is small compared with the electron-ion recombination, one can make an approximation near the end of the onset and start of the cutoff characteristic. The data analysis has only been applied to a limited amount of the present experimental data and yields $\alpha_{CO} \sim 10^{-7}$ to $10^{-6}$ $cm^3/sec$ in the range of mean electron energies 0.8 to 0.2 eV. This is to be compared with the measurements in pure $N_2$ which have been analyzed to indicate $\alpha_{N_2} \sim 10^{-7}$ $cm^3/sec$ over the same range of electron energy.

Provided that the electron attaching impurity content is small, as in these experiments, the electron density is approximately proportional to the square root of the ratio of the electron beam current density to the recombination rate constant. Thus, to produce an electron density of $10^{12}/cm^3$ in CO and $CO/N_2$ mixture will require electron beam current densities of the order of 10 mamps/$cm^2$ at E/N of $10^{-16}$ volt-$cm^2$, corresponding to a mean electron energy of 1/2 volt. The theoretical calculations have shown that these conditions are probably required to achieve reasonable efficiency in pulses of several hundred microsecond duration.

The same small scale apparatus has been used to measure the maximum E/N before breakdown in both "pure" CO and $CO/N_2$ mixtures. This measurement is subject to the detailed electrode configuration in the small scale experiment. Based on previous comparison between data obtained in both the small scale apparatus and more recent large scale experiments, it is certain that the breakdown limits as observed in the former apparatus will provide an underestimate of breakdown for the full scale experiment. The measured breakdown E/N refers to that value of E/N prior to arcing of the sustainer discharge during the E-Beam pulse. The ultimate E/N in CO depends upon the attachment impurity concentration and is obviously increased by the presence of attachment. For the "purest" CO used in these experiments, breakdown was not observed at $E/N < 2 \times 10^{-16}$ volt-$cm^2$ with a corresponding energy input of several hundred joules/litre atmosphere of CO. The corresponding

measurements in pure $N_2$ yielded $E/N < 1.5 \times 10^{-10}$ volt-cm$^2$ with a similar energy density input.

# IV. THEORY

A basic part of this program is the theoretical modeling of the pulsed CO laser for comparison with and understanding of the experimental measurements. A detailed kinetics program has been written to calculate the properties of the output lasing pulse as a function of energy input characteristic, gas density and temperature and cavity properties. This program couples a finite rate kinetics for multilevel anharmonic oscillators with the cavity gain-loss properties and the electron energy input rates. An implicit integration scheme is used to integrate the "master" kinetic equations.

The calculations are carried out in two steps for the excitation of an initially vibrationally cold gas by a top hat discharge profile. First, the gas is vibrationally excited by electron impact excitation and the vibrational energy becomes distributed among the levels of the oscillator (CO) by intramode V-V collisions. During this initial phase, the maximum partial inversion gain is calculated for all vibrational levels and the master equations only include vibrational exchange terms. Once one of the gains becomes large enough to amplify the signal the program switches to the complete kinetic equation including stimulated emission. The translational temperature is allowed to vary as a result of (a) direct excitation of rotation by electrons, (b) V-T deactivation collisions and (c) energy defect in nonresonant collisions. The detailed excitation rates for vibrational excitation of individual levels by the electrons are derived from a solution to the Boltzmann equation applied with the appropriate E/N excitation conditions.

The program output includes time-wise profiles of

1) the stored vibrational energy
2) the lasing energy/power variation
3) the total and instantaneous efficiency defined as lasing power out divided by the input electrical power
4) the gas translational temperature

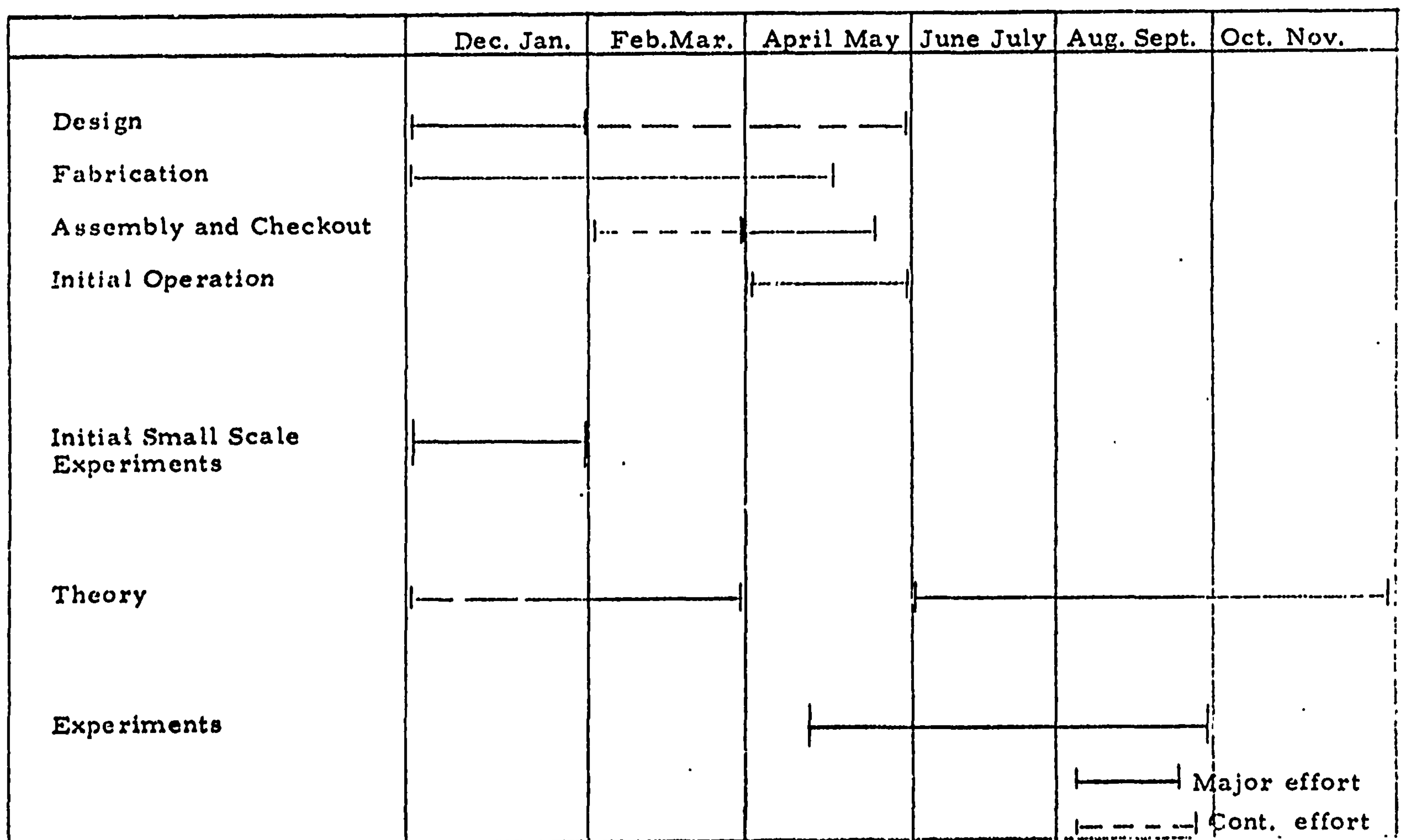
Dec. Jan.
Feb.Mar.
April May
June July
Aug. Sept.
Oct. Nov.
Design
Fabrication
Assembly and Checkout
Initial Operation
Initial Small Scale Experiments
Theory
Experiments
Major effort
Cont. effort

Fig. 1

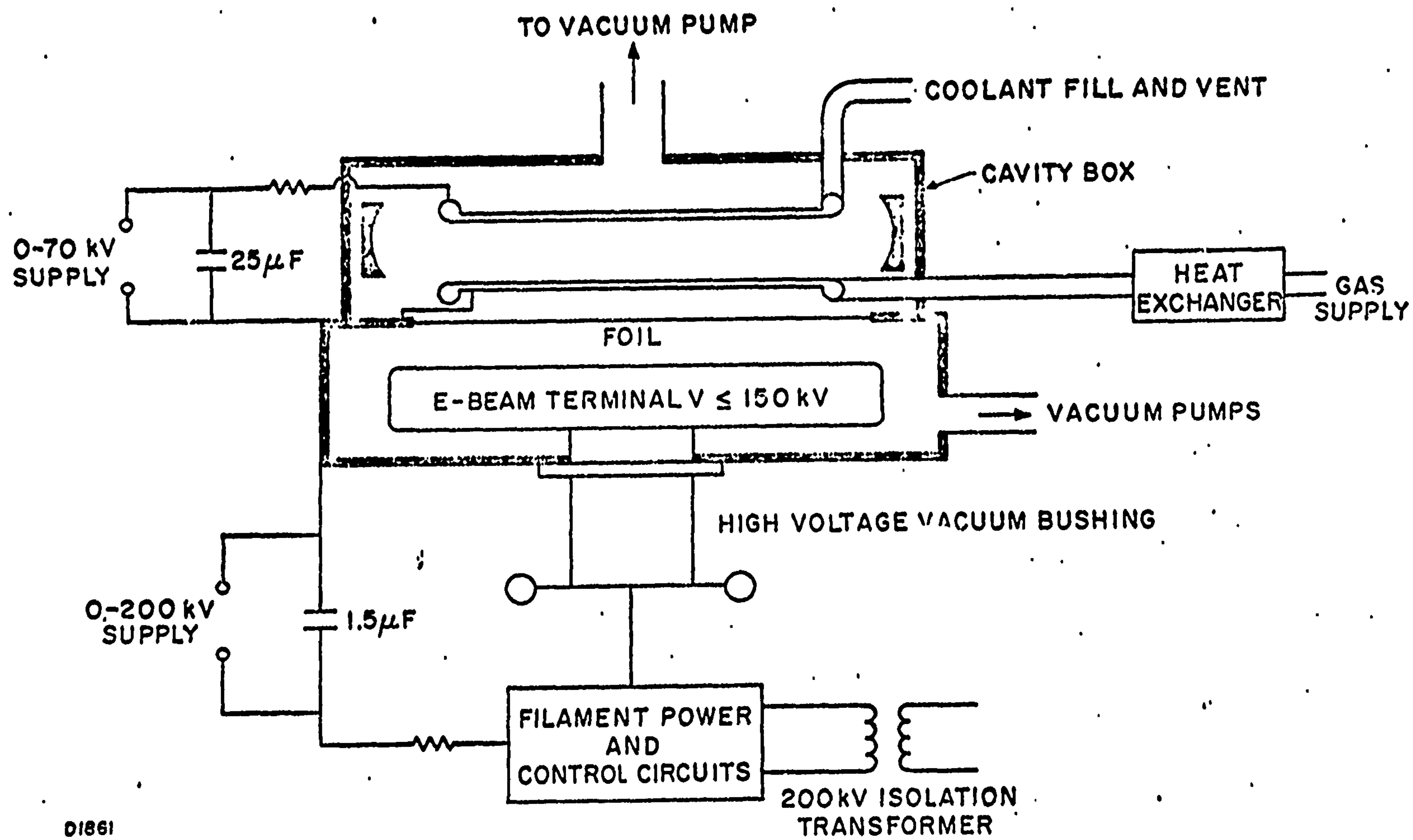
TO VACUUM PUMP
COOLANT FILL AND VENT
CAVITY BOX
0-70 kV SUPPLY
25μF
HEAT EXCHANGER
GAS SUPPLY
FOIL
E-BEAM TERMINAL V ≤ 150 kV
VACUUM PUMPS
HIGH VOLTAGE VACUUM BUSHING
0-200 kV SUPPLY
1.5μF
FILAMENT POWER AND CONTROL CIRCUITS
200kV ISOLATION TRANSFORMER
D1861

Fig. 2

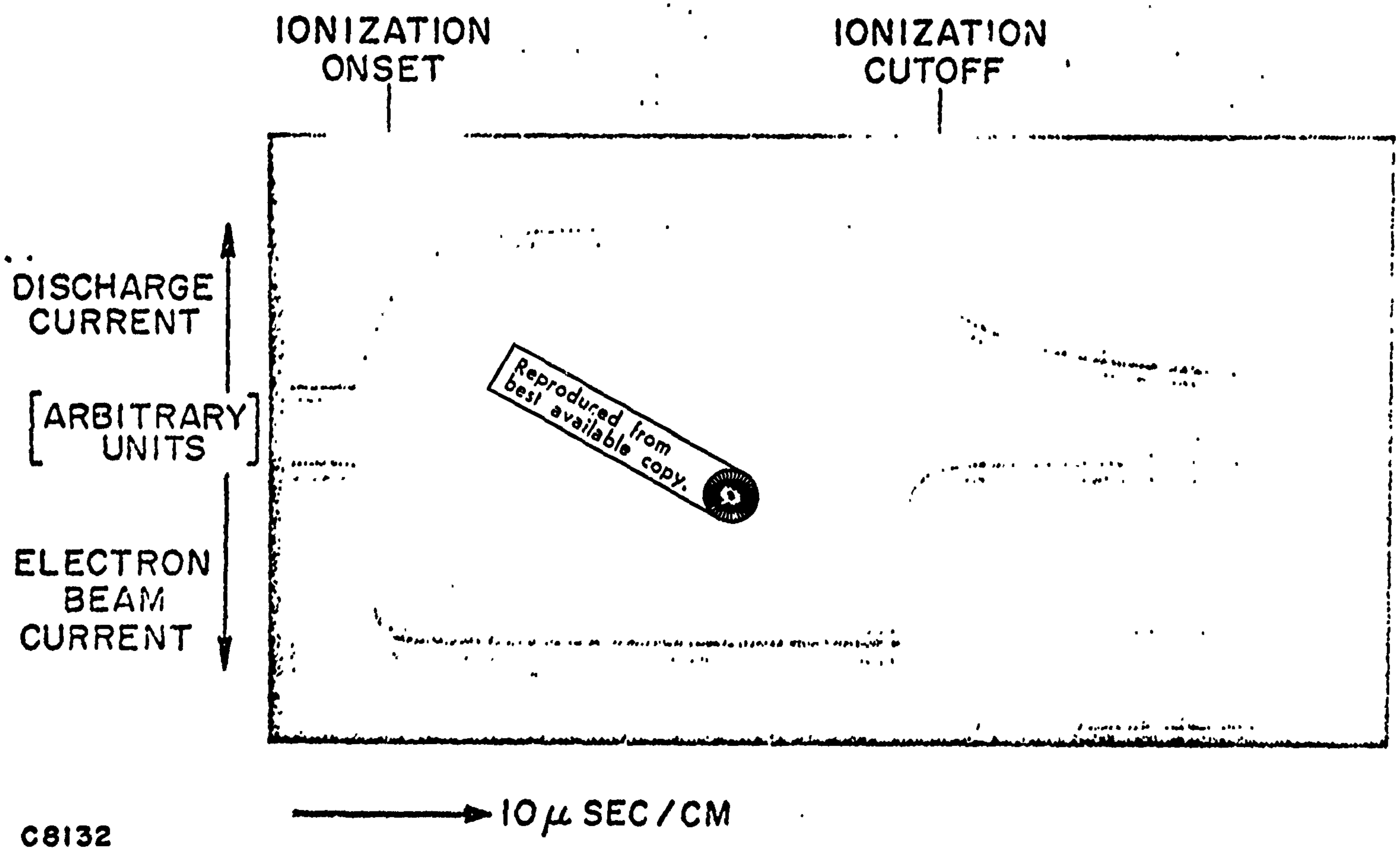
IONIZATION ONSET
IONIZATION CUTOFF
DISCHARGE CURRENT
[ARBITRARY UNITS]
ELECTRON BEAM CURRENT
10 μ SEC / CM
C8132



Fig. 3